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MODERN CONCEPTS OF THE PHYSICAL CONSTITUTION OF COAL

BY
GILBERT H. CADY

PRACTICAL SIGNIFICANCE OF THE PHYSICAL CONSTITUTION OF COAL IN COAL PREPARATION

BY
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MODERN CONCEPTS OF THE PHYSICAL CONSTITUTION OF COAL[1]

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ABSTRACT

The modern concepts of the physical constitution of coal involve megascopic recognition of four primary-type coals—vitrain, clarain, durain, and fusain—and subtypes due to variations of a microscopic order in the physical constitution of the primary-type coals. Most coal beds consist of composite associations of the primary-type coals. The technique of coal description has, in general, not kept pace with the technique of type differentiation. The validity of type classification has not been fully established by chemical evidence, which evidence, however, is strongly suggestive that the differences are real. The practical significance of type variations in coal lies in the fields of coal classification, coal preparation, and coal processing, including hydrogenation.

INTRODUCTION

The concept that coal may have a constitution possible of analysis in terms of its physical components is itself modern. Inquiry into the nature of the physical heterogeneity of coal began within the last twenty-five to thirty years, so that almost any concept in this field is a modern concept.

The study of the physical constitution of coal has attracted relatively few persons of geological training in this country, although rather more in other parts of the world. Lack of interest in the subject appears to be due to the fact that geological ideas in regard to

[1] Address delivered at the Fiftieth Anniversary Celebration, University of Chicago, September, 1941. Presented with the permission of M. M. Leighton, chief, Illinois State Geological Survey.

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coal were established when its use was largely restricted to the high-rank coals. With respect to the variations in the physical constitution of these there was and is little point for concern. This same point of view has, unfortunately, been adopted by geologists in general toward the lower-rank coals, and expansion in the use of these coals has brought little immediate change in the geologist's attitude. Like the higher-rank coals, the coals of low rank were examined geologically and chemically and were used commercially in bulk without consideration of the existence or significance of physical heterogeneity.

However, the wide extension of the use of these coals, the mounting severity of competition, the common failure of the low-rank coals to perform with the same excellence as the higher-rank fuels, and the echoes of research announced abroad are circumstances stimulating curiosity concerning the nature and possible importance of the physical heterogeneity of the low-rank coals.

The present paper will be restricted to a discussion of the physical constitution of the mature coals,[3] namely, those of subbituminous, bituminous, and anthracite ranks. It is assumed that coals that have been subjected to equal amounts of geological vicissitude are of similar rank.

COAL VARIETIES

RANK VARIETIES

Two general categories of variation in coals are widely recognized. In one category are rank varieties,[4] effected by progressive metamorphism. More or less arbitrarily, although carefully, selected chemical criteria are used to differentiate coals of different rank. Physical criteria for differentiation also exist but are more difficult of absolute application.[5] It may be pointed out, however, that rough differentiation on physical grounds long preceded precise differentiation on chemical grounds.

[3] C. E. Marshall, "Contribution to the Comparative Petrology of British and American Coals of Carboniferous Age: Anthraxylon and Vitrinite (Vitrain)," *Fuel in Sci. and Pract.*, Vol. XX (1941), pp. 52–59, 82–91, particularly p. 53.

[4] Marshall, "Standard Specifications of Classification of Coals by Rank. A.S.T.M. Designation: D 388-38," *1939 Book of A.S.T.M. Standards Including Tentative Standards* (Philadelphia: Amer. Soc. Test. Materials, 1939), Part III, pp. 1–6.

[5] L. C. McCabe, "Some Physical Evidences of Development of Rank in Vitrain," *Fuel in Sci. and Pract.*, Vol. XVI, No. 9 (1937), pp. 267–86.

TYPE VARIETIES

More fundamental than variations caused by differences in rank are those caused by differences in the physical constitution or make-up of the coal. Variations in this category[6] produce what have been called "type varieties."

The importance of type variations of coal declines with advancing rank. Thus all anthracite of similar rank displays a great similarity of appearance, even though traces of an original heterogeneity of physical constitution may still be evident when the coal is specially prepared for inspection.[7]

In contrast with the physical homogeneity of the anthracites is the great heterogeneity in constitution of the mature coals of lower rank. It is with these coals that we are particularly concerned.

TYPES OF BITUMINOUS COALS ON THE BASIS OF MEGASCOPIC CRITERIA

BANDED AND NONBANDED COALS

Banded coals.—Inspection of a number of banded coals from various sources generally reveals the presence of four varieties of coal material, which have been called "banded ingredients" by Marie C. Stopes[8]—namely, vitrain, clarain, durain, and fusain (Fig. 1). The banded appearance or structure of all banded coals, whether bright or dull, is found to be due to the presence of layers, lenses, sheets, or fibers of jet-black vitrain or vitrain-like material of small dimensions. Bright-banded coals contain layers, lenses, or sheets of clarain with silky, bright luster between layers or bands of vitrain; dull-banded coals consist of interlayered vitrain and dull durain. A third variety of coal occurring in some beds of coal in benches, layers, or lenses is fusain or mineral charcoal.

Nonbanded coals.—What is commonly regarded as the banding of coals is due almost entirely to the presence of vitrain or vitrain-like

[6] McCabe, "Standard Definitions for Commercial Varieties of Bituminous and Subbituminous Coals, A.S.T.M. Designation: D 493-39," *1939 Book of A.S.T.M. Standards Including Tentative Standards*, Part III, p. 58.

[7] H. G. Turner and H. R. Randall, "A Preliminary Report on the Microscopy of Anthracite Coal," *Jour. Geol.*, Vol. XXXI (1923), pp. 306–13.

[8] "On the Four Visible Ingredients in Banded Bituminous Coals: Studies in the Composition of Coal, No. 1," *Proc. Roy. Soc. London*, Vol. XC (1919), p. 470; Stopes and R. V. Wheeler, *Monograph on the Constitution of Coal* (London: Dept. Sci. and Indust. Research, 1918).

PHYSICAL CONSTITUTION OF BITUMINOUS AND SUBBITUMINOUS COALS

CONSTITUENTS | COALS

MACERALS	PHYTERAL EQUIVALENTS	PRIMARY TYPE COALS ("BANDED INGREDIENTS")		COMPOSITE OR BANDED COALS	
THE INDIVIDUAL PHYSICAL COMPONENT OF COAL, USUALLY BUT NOT ALWAYS OCCURRING IN PHYTERAL FORM.	ANY FOSSIL PLANT FORM OR SECRETION RECOGNIZABLE AS AN ORGANIC ENTITY, EITHER ORGANIZED STRUCTURES (ROOTS, STEMS PETIOLES, LEAVES, REPRODUCTIVE ORGANS, ETC) IN WHOLE OR IN PART, AND SECRETIONS HAVING CHARACTERISTIC FORM (WAXES, RESINS, ETC) GENERALLY WITH NO SPECIAL NAME	EACH COAL IS COMPOSED EITHER OF A SINGLE KIND OF MACERAL, WHICH MAY REPRESENT A SINGLE PHYTERAL OR CONSIST OF AN AGGREGATE OF MACERALS, COMMONLY BUT NOT ALWAYS OF MICROSCOPIC SIZE, AND COMMONLY BUT NOT ALWAYS OF DIVERSE KIND		THESE COALS CONSIST OF INTERLAMINATED AGGREGATES OF PRIMARY-TYPE COALS (BANDED INGREDIENTS). THE BANDED STRUCTURE IS DUE MAINLY TO THE PRESENCE OF VITRAIN OR MICROVITRAIN. THERE ARE TWO MAJOR CLASSES: BRIGHT AND DULL	
		TYPES	VARIETIES	GENERAL VARIETIES	SPECIAL VARIETIES
MORE COMMON MACERALS:	IN BOTH LARGE & SMALL UNITS:	(MAINLY AS INGREDIENTS, BUT MAY COMPOSE THE ENTIRE BENCH OR BED)		BRIGHT BANDED COALS: CONSIST OF-	
Vitrinite (Occurs as Vitrain in bands more than .10-in. thick (2 mm.); as microvitrain in bands 2 mm. to 0.05 mm. thick; and as humic degredation matter less than 0.05 mm. Varities depend on composition but none specifically recognized. Usually contains cell traces.)	Roots, stems, leaves, petioles, etc. (Muralite of various kinds)	**Vitrain (Anthraxylan)** CONTAINS: VITRINITE ± Resinite (At least 2 mm. (0.1-in) thick)	Depending on the kind of plant represented and on presence or absence of resinite.	**Vitrain and** CLARAIN ± minor Durain and minor Fusain. OR **Clarain with** MICROVITRAIN ± minor Durain and minor Fusain.	Determined by the amount of vitrain and its character and thickness, (More than 0.5 in thick banded, 0.5 to 0.1 in. thin banded) and character of clarain. VARIETIES UNNAMED Vitrain may rarely be banded with cannel to form a bright banded cannel.
Fusinite (Occurs as Fusain or as particles or small aggregates in Clarain and Durain. No varieties distinguished) except semifusinite.)	Roots, stems, leaves, petioles, etc. (Muralite of various kinds)	**Fusain** CONTAINS: FUSINITE	Unrecognized	INTERMEDIATE BANDED COALS CONSIST OF-	

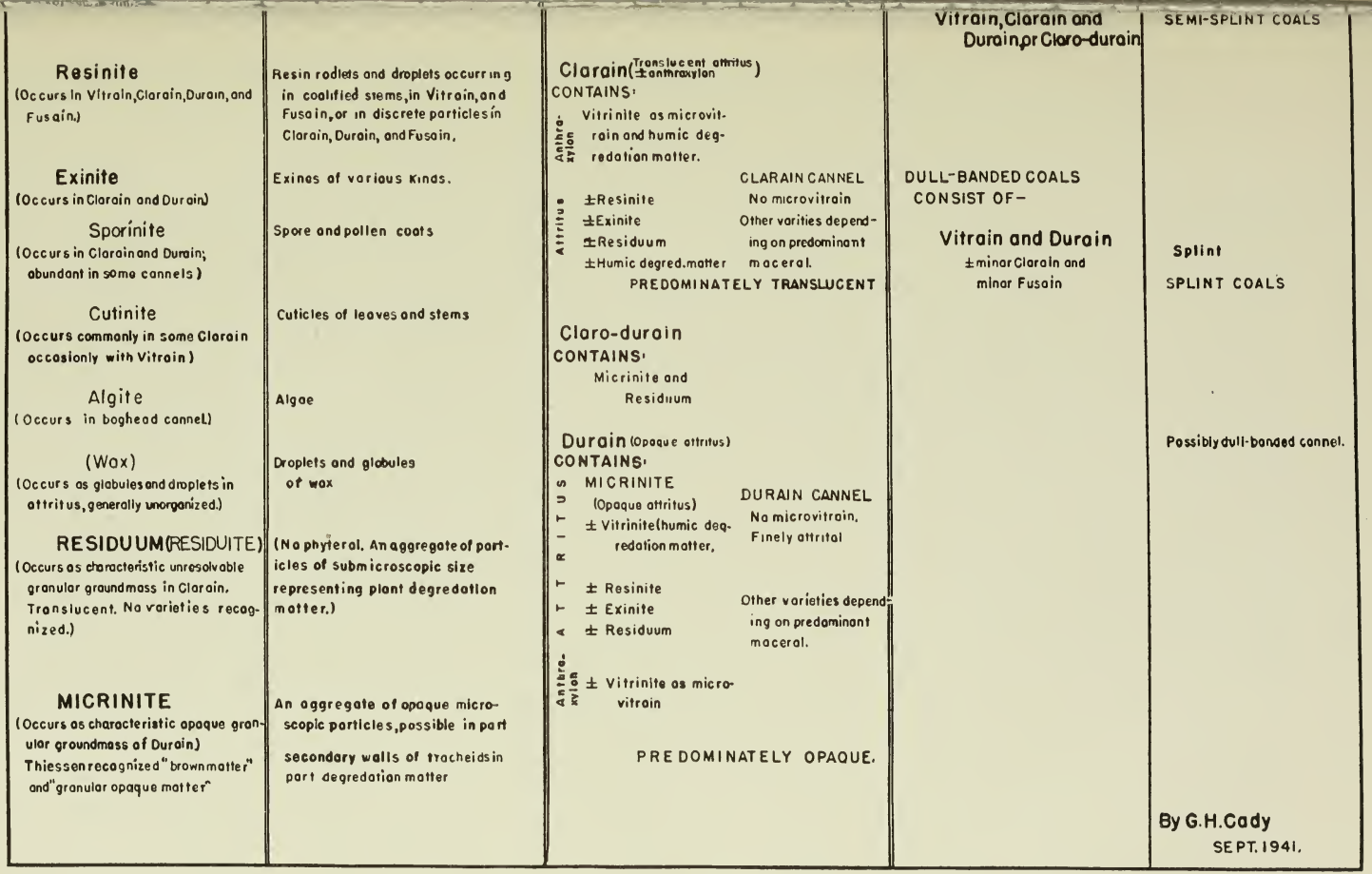
Resinite
(Occurs in Vitrain, Clarain, Durain, and Fusain.)
Resin rodlets and droplets occurring in coalified stems, in Vitrain, and Fusain, or in discrete particles in Clarain, Durain, and Fusain.
Exinite
(Occurs in Clarain and Durain)
Exines of various kinds.
Sporinite
(Occurs in Clarain and Durain; abundant in some cannels)
Spore and pollen coats
Cutinite
(Occurs commonly in some Clarain occasionly with Vitrain)
Cuticles of leaves and stems
Algite
(Occurs in boghead cannel)
Algae
(Wax)
(Occurs as globules and droplets in attritus, generally unorganized.)
Droplets and globules of wax
RESIDUUM (RESIDUITE)
(Occurs as characteristic unresolvable granular groundmass in Clarain. Translucent. No varieties recognized.)
(No phyterol. An aggregate of particles of submicroscopic size representing plant degredation matter.)
MICRINITE
(Occurs as characteristic opaque granular groundmass of Durain)
Thiessen recognized "brown matter" and "granular opaque matter"
An aggregate of opaque microscopic particles, possible in part secondary walls of tracheids in part degredation matter
Clarain (Translucent attritus ± anthraxylon)
CONTAINS:
Anthraxylon
Vitrinite as microvitrain and humic degredation matter.
Attritus
±Resinite
±Exinite
±Residuum
±Humic degred. matter
CLARAIN CANNEL
No microvitrain
Other varities depending on predominant maceral.
PREDOMINATELY TRANSLUCENT
Claro-durain
CONTAINS:
Micrinite and Residium
Durain (Opaque attritus)
CONTAINS:
ATTRITUS
MICRINITE
(Opaque attritus)
± Vitrinite (humic degredation matter,
DURAIN CANNEL
No microvitrain, Finely attrital
± Resinite
± Exinite
± Residuum
Other varieties depending on predominant maceral.
Anthraxylon
± Vitrinite as microvitrain
PREDOMINATELY OPAQUE.
Vitrain, Clarain and Durain, or Claro-durain
DULL-BANDED COALS CONSIST OF—
Vitrain and Durain
±minor Clarain and minor Fusain
SEMI-SPLINT COALS
Splint
SPLINT COALS
Possibly dull-banded cannel.
By G.H.Cady
SEPT. 1941.

FIG. 1

material of small dimensions. Nonbanded coals, on the other hand, contain essentially no vitrain. Cannels are typical examples of such coals, but probably not all nonbanded coals are generally regarded as cannels. Nonbanded coals consist of clarain or durain or of material intermediate between the two.

PRIMARY-TYPE COAL

The varieties of coal which compose the banded and unbanded coal beds, to which the term "banded ingredients" was applied by Stopes in 1919[9] and "rock types" in 1935[10] are regarded by the writer as primary types of coal. This belief is in accordance with what appears to be Stopes's conception of the ingredients as the four fundamental varieties of bituminous coal into which all such coal can be resolved. Whether they are called "primary types," "rock types," or "ingredients" is of minor importance, provided the same implication of terms is maintained. The terms will be used interchangeably in the present paper.

The primary-type coals or ingredients were originally differentiated on the basis of megascopic criteria,[11] which have since been supported to a greater or less degree by microscopic criteria.[12] There has been considerable confusion in understanding and terminology mainly because of what must be regarded as ill-advised[13] initial declarations concerning the microscopic identifications, later largely cleared up,[14] but partly because of the parallel development of a genetic system of terminology in the United States and partly because of a lack of standardization of microscopic technique employed in different parts of the world. This confusion is gradually disappearing; but, unless there is considerable expansion of the meager literature dealing with the subject of the physical constitution of coal, complete clarification cannot be expected for a number of years.

The banded ingredients have been described many times and

[9] "On the Four . . . . ," *op. cit.*

[10] Stopes, "On the Petrology of Banded Bituminous Coals," *Fuel in Sci. and Pract.*, Vol. XIV, No. 1 (1935), pp. 4–13.

[11] Stopes, "On the Four . . . . ," *op. cit.;* Stopes and Wheeler, *op. cit.*

[12] Stopes, "On the Petrology . . . . ," *op. cit.*

[13] Stopes, "On the Four . . . . ," *op. cit.;* Stopes and Wheeler, *op. cit.*

[14] Stopes, "On the Petrology . . . . ," *op. cit.*

fairly recently by the writer.[15] It is unnecessary to repeat definitions and descriptions with which there is familiarity. Consideration will be given, therefore, only to some of the more or less controversial matters involving the identification of these primary-type coal materials.

Vitrain.—As far as the writer is able to discover, there is no disagreement, on the basis of *megascopic* characteristics, in regard to the kind of coal material that Stopes named "vitrain." Controversy has developed mainly as a result of disagreement concerning the validity of the initial *microscopic* characterization of vitrain,[16] some workers having accepted this characterization as valid,[17] others not being willing to do so.[18] Hence, one group of technologists claims that vitrain is composed of structureless material and another that there is no structureless vitrain.

Uncertainty has developed concerning the application of the term "vitrain" to vitrain-like material of small dimensions which may make up a considerable portion of a clarain layer or band. The same material, it is felt, should not be called both "vitrain" and "clarain."

The distinction is obviously mainly one of size. Arbitrary limits will eventually be necessary and some terminology proposed. The writer, since he has already used the term,[19] suggests that the thin vitrain-like bands composing clarain shall be called "microvitrain," meaning small vitrain rather than vitrain necessarily of microscopic width. There is practical justification in setting a limitation between vitrain and microvitrain as it occurs in coal at about $\frac{1}{10}$ inch (2 mm.) with a tolerance of 1 millimeter, for it has been shown[20] that in the natural breakage of coal the thicker vitrain bands tend to break away from the rest of the coal and to concentrate in the small-screen sizes.

[15] "Nomenclature of the Megascopic Description of Illinois Coals," *Econ. Geol.*, Vol. XXXIV, No. 5 (1939), p. 487.

[16] Stopes, "On the Four . . . . ," *op. cit.*

[17] André Duparque, "Structure microscopique des charbons du bassin houiller du nord et du Pas de Calais," *Mem. Soc. géol. du nord*, Vol. XI, Part I (1923), pp. 150–72.

[18] Reinhardt Thiessen, "What Is Coal?" (Cincinnnati: Appalachian Coals, Inc., 1937), pp. 22–26. (Planographed.)

[19] *Op. cit.*

[20] McCabe, "Changes in the Constitution of Illinois Coal through Preparation Processes," *Mining Cong. Jour.*, Vol. XXIII (1937), pp. 18–19.

The minimum width of microvitrain as distinct from attrital humic matter is set at 0.05 millimeter (50 μ) in accordance with the practice followed by Thiessen.[21]

A second reason for differentiating vitrain and microvitrain is in line with certain suggestions made by Thiessen. Although he established no categories of size-differentiation of anthraxylon (the equivalent of vitrain) down to at least 0.05 millimeter (50 μ), nevertheless, he did call attention to a distinction between thick and thin bands. Thus he said:

> While the thicker bands are almost exclusively derived from the wood, periderm, or bark of the stems, the smaller ones may be derived from leaf basis, petioles, rachis, sporophylls and sporangia, as well as from the woody part and barks of the stems.[22]

The tentative selection of about $\frac{1}{10}$ inch as an arbitrary megascopic dimensional boundary between bands of vitrain and microvitrain in the bed, bench, or hand specimen of coal, to satisfy the necessity for quantitative determinations, will probably exclude from vitrain all vitrain-like material not derived from stems and in general will not include in the vitrain the microvitrain characteristic of the smaller broken sizes of coal between the dimensions of about 2 inches and about $\frac{1}{4}$ inch. After coal is crushed to a powder the vitrain-like material present cannot be differentiated as having originated either as vitrain or as microvitrain.

Fusain.—No particular difficulty exists with respect to the identification or the nomenclature of fusain. Fusain may be hard or soft, depending upon whether or not it has been mineralized. Semifusain[23] is material transitional between vitrain and fusain, like a half-charred piece of wood.

Estimation of the quantity of fusain present in a coal is of practical interest in planning for dedusting and dust-settling operations designed to benefit the coal.[24] This can be done by screen analysis

[21] A. C. Fieldner *et al.*, "Methods and Apparatus Used in Determining the Gas, Coke, and By-product Making Properties of American Coals," *U.S. Bur. Mines Bull. 344* (1931), p. 69.

[22] "What Is Coal?" p. 26.

[23] Otto Stutzer and Adolph C. Noé, *Geology of Coal* (Chicago: University of Chicago Press, 1940), p. 71.

[24] Thiessen, "Fusain Content of Coal Dust from an Illinois Dedusting Plant," *Amer. Inst. Min. and Met. Engineers Tech. Pub. No. 664* (1936).

and fusain counts,[25] but the Fuchs method of selective oxidation[26] has been found more practical.[27]

Clarain.—Clarain has proved the most troublesome to identify and describe of the primary-type coals or ingredients. This is mainly because it may be composed very largely of microvitrain. It may be entirely omitted from the picture, as is done by Thiessen[28] and by Erich Stach;[29] or the concept may be redefined and enlarged to include vitrain as well as microvitrain, as was done recently by A. Raistrick and C. E. Marshall.[30] Acceptance of a $\frac{1}{10}$-inch limitation as the minimum width of vitrain may help to allay this uncertainty in identification and description, unless fundamental considerations are at stake not evident to the present writer.

Durain.—It is generally agreed that durain is dull attrital coal, characterized by a high proportion of opaque material.[31] The characteristics of durain, generally called "splint coal" in America, have been described at length by Thiessen, by Thiessen and Sprunk, and by Sprunk and others.[32]

The differentiation of clarain and durain has also given difficulty. When either coal possesses its characteristic appearance, the clarain being bright and the durain dull, there is no great difficulty in their identification. It is the intermediate coals that give difficulty, particularly the rather dull clarain coals. It seems appropriate to designate these by the term "duro-clarain." Attrital coal of this inter-

[25] Bryan C. Parks and L. C. McCabe, "Fusain Content of Fine Sizes of Illinois Coals," *Trans. Ill. State Acad. Sci.*, Vol. XXXIII (1940), pp. 164–68.

[26] W. Fuchs *et al.*, "The Chemistry of the Petrographic Constituents of Bituminous Coal: I. Studies on Fusain," *Penn. State Coll., Min. Indust. Exper. Stat. Bull. 23* (1938).

[27] B. C. Parks *et al.*, "A Comparison of Chemical and Petrographic Methods of Determining the Fusain Content of Illinois Coal" (paper read before the Gas and Fuel Division, American Chemical Society, Atlantic City, September, 1941).

[28] "What Is Coal?" pp. 30–33.

[29] *Lehrbuch der Kohlenpetrographie* (Berlin: Gebrüder Borntraeger, 1935), pp. 23–95.

[30] *The Nature and Origin of Coal and Coal Seams* (London: English Universities Press, Ltd., 1939), p. 180.

[31] *Ibid.*

[32] Thiessen, "What Is Coal?"; Fieldner *et al.*, *op. cit.;* R. Thiessen and George C. Sprunk, "The Origin of the Finely Divided or Granular Opaque Matter in Splint Coals," *Fuel in Sci. and Pract.*, Vol. XV (1936), pp. 304–15; Sprunk *et al.*, "Splint Coals of the Appalachian Region—Their Occurrence, Petrography and Comparison of Chemical and Physical Properties with Associated Bright Coals," *U.S. Bur. Mines Tech. Paper 615* (1940).

mediate character, it is believed, composes the attrital portion of the coals called "semisplint" by Thiessen.[33]

There is a distinction of possible importance between splint coal and durain. Splint coal was apparently regarded by Thiessen[34] as one of the varieties of banded coals containing both anthraxylon (vitrain) and attritus. It is the name of a mixed or composite coal and not the name simply of the dull, attrital part of such coal, which is durain.

In England durain is commonly known by the name "hard coal" or "hards,"[35] occurring as benches in coal beds otherwise consisting of bright-banded coals, vitrain, and clarain. In Germany this kind of coal is called *Mattkohle*.

CANNELS

Cannels are attrital, finely microclastic, nonbanded coals. They may belong either to the clarain or to the durain primary types of coal. This classification depends in a general way upon whether they appear bright or dull, but final decision depends upon whether thin sections of the coal are translucent or opaque. The name carries certain connotations concerning fineness of grain, density, fracture, luster, and temperature of ignition that are generally applicable. A considerable variety of such coals exist, which can be conveniently classified as either clarain cannels or durain cannels.[36] The subordinate character of the components of cannel is subject to considerable variation and determines the subvariety of such cannel. Thiessen lists six such varieties.[37]

THE COMPOSITE COALS

In their most common mode of occurrence the primary-type coals or ingredients are associated as contiguous layers to comprise composite varieties of coal in beds or benches. Conversely, the composite coals are megascopically resolvable into two or more of the primary-type coals or ingredients.

Each ingredient may compose an entire bed or bench of coal, but such a bed or bench of coal is not a composite coal.

[33] "What Is Coal?" p. 35.

[34] *Ibid.*, pp. 30–33.

[35] Raistrick and Marshall, *op. cit.*, p. 200.

[36] Thiessen, "Recently Discovered Methods of Research in the Constitution of Coal and Their Application to Illinois Coals," *Ill. State Geol. Surv. Bull. 60* (1931), p. 124.

[37] *Ibid.*, p. 125.

THE MICROSCOPIC CONSTITUENTS: MACERALS AND PHYTERALS

Primary-type coals are not themselves of uniformly similar composition, because of variations in their physical constitution, the nature of which it is possible to determine only by microscopic examination of the coal. This statement introduces consideration of the macerals and "phyterals."

Macerals have been called by Stopes[38] the "petrologic units" of the rock types, corresponding to minerals in sedimentary and igneous rocks. The writer has believed for some time that there is need for another term to designate plant forms or fossils in coal as distinguished from the material of which the fossils may be composed, as long as this is organic matter. To meet this need the term "phyteral" (*Φυτον*, Gr. meaning "plant" and *-eral* in "mineral") is proposed. In general, macerals seem to be less persistent as individual substances than are phyterals as fossil forms, since phyterals may be discovered in high-rank coals in which macerals no longer appear to exist as distinct substances. The term "phyteral" should be used as essentially equivalent to the phrase "coal fossil" or "coalified fossil" or as "fossil" is used in descriptions of sedimentary rocks.

The composition of the primary coal types is determined by the nature of the macerals of which each is composed.

THE PHYTERALS AND MACERALS OF THE PRIMARY COAL TYPES

Vitrain is composed to a greater or less extent of the maceral vitrinite.[39] According to Stopes, vitrinite has a number of meanings, but the material is primarily a "translucent golden gel." In some vitrain certain phyterals are present which consist of traces of cellular structure representing cell walls of various parts of the stems or roots of plants. This cellular structure—the form not the substance—it is proposed to designate by the term "muralite" (*muralis*, "of walls").

The plants and plant parts and forms represented by muralite in vitrain have been described at length by H. G. A. Hickling and C. E. Marshall,[40] by Raistrick and Marshall,[41] and by Thiessen.[42]

[38] "On the Petrology . . . . ," *op. cit.*, pp. 6–7. [39] *Ibid.*

[40] "The Microstructure of the Coal in Certain Fossil Trees," *Trans. Inst. Min. Engineers*, Vol. LXXXIV, Part II (1932), pp. 13–23; Vol. LXXXVI, Part II (1933), pp. 56–75.

[41] *Op. cit.*, pp. 181–90. [42] "What Is Coal?" pp. 22–26.

It is uncertain whether or not the substances represented by these cellular forms of muralite actually exist as macerals distinct from the vitrinite. If they do, the character of the vitrain presumably varies with variation in the character of the maceral.

Some vitrain contains in addition to vitrinite more or less resinite,[43] which is the substance of resin rodlets or other forms of resinous secretory matter which occupied cell cavities in the tissues which have been vitrinized. Occasionally resinite will make up a considerable portion of a vitrain band. Resinite has somewhat different properties than vitrinite, as has been shown by studies made by Thiessen and Sprunk[44] on the effect of heat on coals as revealed by the microscope.

The attrital coals—durain and clarain—are commonly composed of a variety of plant materials (macerals) of various derivations. Thiessen has listed the components of attrital coals as "humic degradation matter, small fragments of plant tissue, cuticles, spore and pollen exines, resin particles, and mineral matter."[45] Such coals also may contain fragments of fusain.

The distinctive feature of the components of clarain is their translucency in thin sections. Durain, on the other hand, is prevailingly opaque.

Composing clarain, besides the macerals which represent recognizable phyterals or plant forms, there is usually a groundmass of translucent material, the units of which are of submicroscopic size, which constitutes the "residuum" (residuite?) of Stopes.[46] Clarain may also contain some opaque matter, the "micrinite" of Stopes.

The components of durain—the essential ingredient of splint coals—are much the same as those of clarain except that there is a large proportion of submicroscopic material consisting predominantly of opaque micrinite.

THE SIGNIFICANCE OF MACERALS IN THE DESCRIPTION AND CLASSIFICATION OF COALS

The megascopic classification of bituminous coal is determined by the ingredients or primary-type coals that are present. More precise

[43] Stopes, "On the Four . . . . ," *op. cit.*

[44] "The Effect of Heat on Coal as Revealed by the Microscope," *Fuel in Sci. and Pract.*, Vol. XIII (1934), pp. 116–25.

[45] Fieldner *et al.*, *op. cit.*, p. 23. [46] "On the Petrology . . . . ," *op. cit.*, pp. 6–7.

classification is dependent upon microscopic determination of the identity and relative abundance of the macerals of which the ingredients may be composed.

The individuality of the macerals is indicated in a number of ways: by the fact that they are the substance of forms (phyterals) having organic individuality; by their physically individual and peculiar properties; and by the fact that coals of the same rank but of different physical composition differ in properties and behavior.

Subvarieties of the ingredient or primary-type coals result from characteristic concentrations of individual macerals, giving the coal special and specific properties.

TECHNIQUE OF COAL STUDY

MICROSCOPIC TECHNIQUE

Microscopic technique in the study of coal has not changed materially for many years,[47] but the quality of the tools has greatly improved, and the purpose of such studies has changed. Three methods have long been employed for the preparation of coal for examination by the microscope: the polished surface,[48] thin sections,[49] and macerated residues.[50] In England and America thin sections are preferred, if they can be made, because their use makes possible more certain identification of the macerals and phyterals. On the Continent less use is made of thin sections, with some important exceptions.

[47] Stach, *op. cit.*, p. 129; Thiessen and Sprunk, "Microscopic and Petrographic Studies of Certain American Coals," *U.S. Bur. Mines Tech. Paper No. 564* (1934), p. 10; Thiessen, "Microscopic Study of Coal" in David White and Reinhardt Thiessen, "The Origin of Coal," *U.S. Bur. Mines Bull. 38* (1913), pp. 187–304; Thiessen *et al.*, "Preparation of Thin Sections of Coal," *U.S. Bur. Mines Inf. Circ. No. 7021* (1938); W. Hutton, "Observations in Coal," *Phil. Mag.*, Vol. II (1833), pp. 302–4; also *Proc. Geol. Soc. London*, Vol. I (1884), pp. 415–47.

[48] Duparque, *op. cit.;* H. Winter, "The Examination of Coal by Reflected Light," *Fuel in Sci. and Pract.*, Vol. II (1923), pp. 78–82. (Previously published in German, *Glückauf*, Vol. XL [1913], pp. 1406–13.)

[49] Hutton, *op. cit.;* Thiessen *et al.*, *op. cit.;* Winter, *op. cit.*

[50] Franz Schultze, "Über des Verkommenwohlerhaltenes Cellulose im Braunkohle und Steinkohle," *Ber. kgl. Akad. d. Wissensch. Berlin* (1885), pp. 676–78; C. W. von Gümble, "Beiträge zur Kenntnis der Textureverhältnisse der Mineralkohlen," *Sitzungsber. kgl. bayr. Acad. Wissensch.* (München), Vol. XIII (1883), pp. 111–216; Hutton, *op. cit.*

TECHNIQUE OF DESCRIPTION AND CLASSIFICATION

Megascopic description.—Megascopic description of the composite or banded coals in accordance with specifications based upon the data of physical constitution has not been standardized. Suitable nomenclature, were it set up, would serve as a short cut to the description of special varieties of coal. At present the only special variety of banded coal to which a name with technical significance has been applied is splint coal. The generalized names "bright banded" and "dull banded" are useful but give little idea concerning the specific characteristics of a particular bright- or dull-banded coal.

The purpose of description is twofold: First, it should provide information in regard to the coal which has significance in terms of utilization or adaptability for utilization and, second, its purpose is technical and scientific, to provide a basis for comparison and classification.

In order to meet the requirements of megascopic description it is believed that any schedule of descriptive procedure applied to a banded or composite variety of coal should include provision for supplying the following information: (1) whether the coal is bright or dull banded; (2) the relative amount of each of the ingredients or primary types of coal; (3) the prevailing width of the vitrain bands —in many cases the number of such bands can be stated; (4) the amount of microvitrain in the clarain and durain; (5) the character of the attrital portion of the clarain and the durain (silky, dull black, grayish-black); (6) the amount and mode of occurrence of the fusain in layers, sheets, lenses, or particles; and (7) the character and distribution of the mineral matter in the bands and layers of the ingredient coals.

Only as systematic description and type specimens become available will an orderly grouping of the composite or banded bituminous coals be achieved.

FIELD DESCRIPTION OF COALS

The conventional practice with respect to field description of coal beds has shown little change in recent years, in contrast to the improvement in laboratory description. Coal beds are rarely described in the field in terms of their physical constituents, so that in general

the descriptions fall far short of providing information suitable for megascopic classification or for indicating the probable behavior of the coal in preparation and utilization.

DESCRIPTION BASED UPON MICROSCOPIC EXAMINATION

Description of column samples.—The graphic method of describing the coal in columns cut from the bed has had fairly wide use.[51] Coal-bed profiles based upon microscopic examination of the coal appear in the works of F. L. Kühlwein, E. Hoffman, and E. Krüpe,[52] G. Roos,[53] Adam Drath and Stanislaw Jaskowski,[54] and R. G. Koopmans.[55]

The United States Bureau of Mines for about ten years has employed a graphic profile system of describing column sections of coal beds.[56] The profile is plotted on the basis of microscopic examination of units of about 20 millimeters of the column. Types of coal are delineated as bright, semisplint, or splint. Subtypes are set up on the basis of the amount of anthraxylon and attritus present, irrespective of the size of the anthraxylon (vitrain and microvitrain) bands. The width of banding is plotted as coarse, fine, or microbanded. Text descriptions accord with data shown in the graphic section.

The profile method has also been very commonly used in plotting megascopic variations in measured sections of coal beds. Numerous profiles of British coal beds appear in the reports of the Physical and Chemical Survey of the National Coal Resources.[57] Graphic profiles

[51] F. L. Kühlwein, "Bedeutung der angewandten Kohlenpetrographie für Kohlengewinnung, Kohlenaufbereitung, und Kohlenveredelung," *Compt. rend. deuxième Cong. p. l'avance d. études strat. carbonifère, Heerlen, 1935,* Vol. II (1937), pp. 539–601.

[52] "Durchführung und praktische Bedeutung planmässig Kohlenpetrographische Flozprofiluntersuchungen," *Glückauf,* Vol. LXX (1934), pp. 1–28, 32–41.

[53] "Comparative Researches on the Variation of the Constituents of Coal of One Seam from South Limburg (the Netherlands)," *Compt. rend. deuxième Cong. p. l'avance d. études strat. carbonifère, Heerlen, 1935,* Vol. II (1937), pp. 1106–27.

[54] "Petrographical Investigations of the Otto Coal Bed, Radzionkow Mine, Upper Silesia," *Ann. Polish Geol. Soc.* (Krakow), Vol. XII (1936), pp. 685–77 (Polish, with Eng. summary).

[55] "Petrographische Profile niederlandischer Flöze," *Compt. rend. deuxième Cong. p. l'avance d. études strat. carbonifère, Heerlen, 1935,* Vol. II (1937), pp. 523–26.

[56] Fieldner *et al., op. cit.,* p. 66.

[57] Koopmans, "The Northumberland and Durham Coalfield," *Dept. Sci. and Indust. Research, Phys. and Chem. Surv. Nat. Coal. Resources No. 41* (1937), p. 9; and numerous other reports of similar character by this department.

are the standard method used by the United States Geological Survey[58] for delineating thickness of beds and the distribution and thickness of interbedded impurities, but the physical constitution of the coal itself is not shown graphically in publications of that survey.

DESCRIPTION OF PREPARED COALS

The technique of measuring the quantity of the various primary-type coals in masses of broken coal is unsatisfactory. Screening and counting of particles of similar size will achieve the desired results but are very laborious.[59] The Fuchs's chemical method of fusain determination has been mentioned.[60] The accurate measurement of the quantity of vitrain, clarain, and durain, as well as fusain, in small sizes of broken coal is a matter of critical importance, if the relative quantity of these primary-type coals is significant in utilization, as has been claimed by James Lomax,[61] O. de Booseré,[62] M. Legraye,[63] and McCabe and associates.[64] This problem is under investigation at the present time in Urbana.

PALEOBOTANY AND THE PHYSICAL CONSTITUTION OF COAL

The physical constitution of coal has a closely knit relationship to paleobotany. Three lines of investigation have proved mutually fruitful within recent years. These are, first, the study of residues, particularly spore coats, obtained by the maceration of coal;[65] sec-

[58] Frank S. Parker and David A. Andrews, "The Mizpah Coal Field, Custer County, Montana," *U.S. Coal Surv. Bull. 906-C* (1939), Pls. XXVIII–XL; and numerous other reports on coal fields by other authors.

[59] Parks and McCabe, *op. cit.* [60] Fuchs *et al.*, *op. cit.*

[61] "Further Researches in the Microscopical Examination of Coal, Especially in Relation to Spontaneous Combustion," *Trans. Inst. Min. Engineers*, Vol. XLVI (1913–14), pp. 592–635.

[62] "Sur les constituants macroscopiques des charbons campanois," *Ann. d. mines de Belge*, Vol. V (1926), pp. 522–27; in English in *Fuel in Sci. and Pract.*, Vol. V (1926), 522–27.

[63] *Les Constituants des charbons, leur influence sur quelques propriétés industrielles* (Paris: Dunod, 1933).

[64] McCabe, "Illinois Coals. Constitution. Importance with Reference to their Utilization," *Mech. Engineering* (March, 1938), pp. 217–21; McCabe *et al.*, "Banded Ingredients of No. 6 Coal and Their Heating Value as Related to Washability Characteristics," *Ill. State Geol. Surv. Rept. of Inv. No. 34* (1934), p. 42.

[65] James M. Schopf, "Spores from the Herrin (No. 6) Coal Bed in Illinois," *Ill. State Geol. Surv. Rept. Inv. No. 50* (1938).

ond, the study of coal-ball petrifactions, large collections of which have become accessible to paleobotanists during the past decade, largely owing to their initial identification by the late Professor A. C. Noé;[66] and, third, the study of vitrain bands, representing the coalified solid portion of stems of various plants.[67]

CHEMICAL INDIVIDUALITY OF THE PHYSICAL COMPONENTS OF COAL

For evidence of the chemical individuality of the physical components of coal essentially the only sources, for American coals at

TABLE 1*

ANALYSES OF A FACE SAMPLE AND SAMPLES OF HAND-PICKED VITRAIN, CLARAIN, DURAIN, AND FUSAIN FROM HERRIN (NO. 6) BED COAL NEAR WEST FRANKFORT, FRANKLIN COUNTY, ILLINOIS

Kind	Lab. No.	Moisture	Vol. Mat.	Fixed Carb.	Ash	H	C	N	O	S	B.t.u.	Unit B.t.u.
Face	B-26213	8.9	35.3†	48.8	7.0	5.6	68.6	1.5	15.9	1.4	12,170	
			38.8‡	53.5	7.7	5.0	75.3	1.6	8.9	1.5	13,360	
			42.0§	58.0	.....	5.4	81.5	1.7	9.7	1.7	14,470	14,622
Vitrain	C-1999	9.0	31.6	58.5	0.9	5.57	74.65	1.71	16.45	0.72	13,009	
			34.7	64.3	1.0	5.02	82.03	1.88	9.28	0.79	14,206	
			35.1	64.9	.....	5.07	82.85	1.90	9.38	0.80	14,438	14,476
Clarain	C-1995	8.3	31.1	46.1	14.5	5.08	62.90	1.60	13.97	2.00	11,272	
			33.9	50.3	15.8	4.53	68.59	1.74	7.20	2.18	12,292	
			40.3	59.7	.....	5.39	81.47	2.07	8.46	2.59	14,600	14,888
Durain	C-1996	3.7	49.9	42.8	3.6	6.29	77.06	1.56	10.03	1.45	14,249	
			51.8	44.5	3.7	6.11	80.01	1.62	7.00	1.51	14,795	
			53.8	46.2	.....	6.34	83.13	1.68	7.29	1.56	15,371	15,467
Fusain	C-1997	8.1	8.4	79.8	3.7	3.11	85.56	0.63	6.41	0.64	13,800	
			9.1	86.9	4.0	2.73	89.70	0.66	2.41	0.67	15,011	
			9.5	90.5	.....	2.83	92.27	0.69	2.51	0.70	15,632	15,716

* Face sample analyzed by U.S. Bureau of Mines; others by Analytical Division, Illinois State Geological Survey.

† As received. ‡ Moisture free. § Moisture and ash free.

least, are the data supplied in the conventional proximate and ultimate forms of analysis. There are gradually being assembled in the laboratories of the United States Bureau of Mines and the Illinois State Geological Survey, and possibly in others, analytical data relative to the primary-type or ingredient coals. The ingredients can be

[66] "Review of American Coal-Ball Studies," *Trans. Ill. Acad. Sci.*, Vol. XXIV (1931), pp. 317–20.

[67] Marshall, "Contribution to . . . . ," *op. cit.;* Thiessen, "What Is Coal?" Raistrick and Marshall, *op. cit.;* Hickling and Marshall, *op. cit.*

separated relatively easily by hand in quantities sufficiently large for purposes of analysis. The resulting analyses often show interesting relationships, but the amount of data does not justify more than suggestive generalizations (Table 1).

Inspection of Table 1 reveals that clarain and the face sample, except for the high ash content of the clarain, are essentially alike. In contrast, the ash content of the vitrain is very low; the fixed and total carbon values are higher, and the hydrogen value somewhat lower, than in clarain and in the whole coal. Durain is characterized by a reversal of the fixed-carbon and volatile-matter relationship as compared with the other coals. Another sample of durain from the same mine gave essentially duplicate values. Fusain has the highest fixed-carbon and total-carbon values—each above 90 per cent—and a very low hydrogen content. These analyses indicate the nature of the evidence concerning the chemical characteristics of the ingredient coals that may be supplied by the commercial types of analysis.

Such data as these provoke the curiosity of the coal geologist concerning the real chemical structures represented by the coal macerals and the ingredient coals. It will be impossible to define these materials chemically until a large volume of proximate and ultimate analytical data is assembled or until the true chemical structure is systematically investigated.

PRACTICAL SIGNIFICANCE OF THE PHYSICAL CONSTITUTION OF COAL

COAL CLASSIFICATION AND DESCRIPTION

Certain phases of the classification of coal into types are perhaps mainly of academic interest, but it is believed that development and general acceptance of such a classification will result in improved technique in laboratory and particularly in field description. Such acceptance probably must precede the general adoption of discriminating methods of selection in the preparation and processing of subbituminous and low-rank bituminous coals, comprising so large a part of the national fuel reserves in the central and western states.

COAL PREPARATION

Conventional coal preparation is concerned with coal size and the separation of coal from associated mineral impurities. Coal itself

is generally regarded as a more or less uniform substance. An important concept was added to the technique of coal production, when Stopes in England called attention to the existence of the ingredient coals as distinct and separable physical entities.

With the development in recent years of special combustion equipment, particularly the underfeed domestic stoker, demands have arisen for specially prepared fuel requiring discriminating methods of preparation. Primarily, this has been a matter of size control, but occasionally special devices are installed to remove fusain from the small sizes of coal, and special means have in some cases been taken to improve the character of the coal by changing the physical constitution. Dr. L. C. McCabe in an accompanying paper of this series explains more fully some of the activities of the Illinois State Geological Survey resulting from a knowledge of the variations in the physical constitution of coal.

COAL PROCESSING

Coal processing includes all treatment of coal for commercial use whereby its character is modified by heat, pressure, or chemical means. In this category are the familiar procedures of carbonization, briquetting, and hydrogenation.

Carbonization.—Studies, explained in some detail by G. C. Sprunk, have been made by the United States Bureau of Mines,[68] which demonstrate that there is considerable difference in the coking properties of coal because of variation in type. As far as is known by the writer, no commercial scale attempt has been made to modify the type of coal used by selective preparation, except that possibly certain parts or benches of a coal bed may be selected or rejected.

Briquetting.—The briquetting properties of the coal ingredients obtained by hand picking have been investigated by R. J. Piersol[69] of the Illinois State Geological Survey. The best briquets were made from clarain, which approximated the character of the face sample of the whole coal. Pure vitrain made a poor briquet, and briquets

[68] Fieldner *et al., op. cit.*

[69] "Briquetting Illinois Coal without a Binder by Compression and Impact: Preliminary Report of a Laboratory Investigation," *Ill. State Geol. Surv. Rept. Inv. No. 31* (1932); "Briquetting Illinois Coal without a Binder: Second Report of a Laboratory Investigation," *Ill. State Geol. Surv. Rept. Inv. No. 36* (1935).

made from durain were somewhat less durable than those made from clarain. Fusain will not make a briquet when pure; it can be added to other coal up to 20 or 25 per cent, however, and the coal will still produce a satisfactory briquet, which, it is claimed, has a considerably reduced tendency to smoke.

Hydrogenation.—Investigations of the comparative usefulness of the coal ingredients for hydrogenation have been carried on by the United States Bureau of Mines[70] and will be discussed by Mr. Sprunk in another paper. The results of these investigations make it appear probable that, if the hydrogenation of coal eventually becomes an important means of producing motor fuel and oil in this country, the largest possible yield from subbituminous and bituminous coals can be obtained only by the selection and concentration of certain physical components of the coal.

CONCLUSION

One cannot expect to find in a threshold science such as this the universal agreement in theory, definitions, objectives, and practice characteristic of sciences that have long since passed the threshold, explored the interior, settled into complacent domesticity, and even worn holes in the carpet. For too long the traditional point of view has dominated the academic viewpoint toward the caustobioliths. This traditional point of view regards coal almost entirely as a problem in geological history, with interest mainly directed toward achieving a complete understanding of the origin of coal beds. Even in this field the problem of the origin and nature of coal itself is usually neglected. This abstract conventional consideration of coal is likely to give little attention to the possible relationship between the visible, but largely ignored, physical heterogeneity of the medium- and lower-rank coals and the problems of coal preparation and utilization.

[70] C. H. Fisher *et al.*, "Hydrogenation of the Banded Constituents of Coal: Fusain," *Indust. Eng. Chem.*, Vol. XXXI (1939), pp. 190–95; "Hydrogenation of Cannel Coals and Their Petrographic Constituents," *Fuel in Sci. and Pract.*, Vol. XIX (1940), pp. 84–89; "Hydrogenation of Anthraxylon (Vitrain) from Peat, Brown Coal, Lignite, Subbituminous Coal, Bituminous Coal, and Anthracite," *ibid.*, pp. 132–33; "Hydrogenation of the Banded Constituents of Coal: Attrital Matter and Anthraxylon," *Indust. Eng. Chem.*, Vol. XXXI (1939), pp. 1155–61.

LOUIS C. McCABE

PRACTICAL SIGNIFICANCE OF THE PHYSICAL CONSTITUTION OF COAL IN COAL PREPARATION[1]

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ABSTRACT

The petrographic investigations of coal of the last two decades have stimulated applied research in the field of preparation and utilization. Definition of the different types and varieties of coal was followed by the accumulation of a body of information on the specific physical characteristics.

Differences in specific gravity, conductivity, and friability have been utilized in commercial and laboratory preparation to separate coals into their component parts. The availability of quantities of the different types in concentrated form has made large-scale combustion research possible. Laboratory tests for ignition temperature, agglutinating value, and swelling index are being perfected and, when correlated with coking, briquetting, and combustion practice, will facilitate the solution of problems arising in these fields.

INTRODUCTION

The petrographic investigations of the last two decades have stimulated applied research in the field of coal preparation and utilization and have clarified a number of combustion problems which were not previously understood. The petrographic method as applied to coal preparation and utilization may now be directed toward improving, refining, and expanding the use of coal.

After the initial observation that there were differences in the appearance of coal, it followed that these differences should be submitted to measurement. The measurements employed were naturally those which had been applied and found valuable in the classification of the other economic minerals and rocks.

Among the most useful physical tests applicable to coal are those which measure friability, grindability, specific gravity, and weathering characteristics. Of equal importance are measurements which will permit the prediction of the behavior of coal when heat is applied in the presence or absence of oxygen.

[1] Address delivered at the Fiftieth Anniversary Celebration of the University of Chicago, September, 1941.

Friability is an important characteristic of coal from the time the seam is opened to production until the coal is consumed. This characteristic may be a phenomenon of rank which is reflected in the entire coal seam, as in the Pocahontas coals, or a reflection of type with many friabilities in the same seam, as in the banded coals of the eastern interior coal fields. It is the latter type with which this paper is concerned.

EFFECT OF PETROGRAPHY ON MINING AND PREPARATION

A seam high in fusain or vitrain responds more readily to cutting and shooting than does one high in clarain or durain. Not only does the petrographic nature affect the cost of mining the coal, but it may be an important factor in the safety of the mine and in the amount of salable coal that may be taken from it. The dusty coal mines in the high volatile fields are in the coal beds high in fusain. Mines in block or splint (durain) coals are not normally dusty. In general, mines working nonbanded coals—that is, splint-, cannel-, and clarain-type coals—are free from dust. Generally the cost of shooting such coal is high, but the proportion of lump is greater than in mines containing a large percentage of vitrain and fusain where preparation demands the removal of dust; as much as 5 per cent of the production may be lost in the preparation plant due to the removal of dust. Such dusts are largely fusain, for which there is no ready market. Because of differences in the friability of the constituents, coals of the banded type may frequently be screened into several increments, each differing from the other and all unlike the parent-seam. Thus it is possible for a single coal bed to produce a 100-mesh to 0-dust which is 75 per cent fusain, a $\frac{1}{8}$–100-inch-mesh product which is 80 per cent vitrain, and a 3–2-inch nut coal which is 85 per cent clarain. Another mine employing selective mining may produce a 6-inch lump coal which is almost entirely splint or durain and a 6-inch to 0 size which is of the bright banded type. These differences in friability give rise to numerous problems in the marketing and utilization of coals. The difficulties encountered in segregation of coal constitute a problem not only of size but also of the petrographic character of the size.

PROCESSING AND UTILIZATION

Fusain is noncoking and in excess of 15 or 20 per cent acts to weaken the structure of both coke and briquettes, but it has been observed that in smaller quantities the addition of it to the charge of a coke oven may be beneficial to the coke structure. The numerous minor fractures are distributed around each individual fusain particle instead of being combined to form the major fractures characteristic of highly fingered coke.

The sizing practice employed in parts of the Illinois field concentrates vitrain in the sizes used for domestic stoker fuel. In some instances, particularly in mild weather, when the stoker operates infrequently, coke is formed from the vitrain more rapidly than it is burned. Some producers have overcome this tendency by crushing the larger clarain sizes, which are free burning, and adding them to the coal produced in normal screening practice.

A more refined procedure, based on the difference in friability of the banded ingredients and affording closer control of the products than is possible in the normal course of mining and screening, was developed by Edwin Hoffman.[2] In this process, which was in the pilot-plant stage in 1932, the coal is passed through a hammer mill and then screened into fractions in which the various coal components are concentrated. This preparation made it possible to control carefully the coking process in which bright coal was used and provided lump domestic fuel from the associated dull coal (durain).

Because of the low grinding costs, coals which can be readily pulverized are usually specified for powdered-fuel plants. A recent United States Bureau of Mines publication concerned with this problem reports on the energy consumed in pulverizing the four coal constituents.[3]

FRIABILITY OF COAL CONSTITUENTS

Contrary to general belief, the ash-bearing constituents are not always most resistant to crushing, as was shown in tests of coal

[2] "Die petrographischen Kohlenbestandteile und ihre aufbereitungstechnische Trennung," *Jahr. d. preuss. geol. Landesanstalt*, Vol. LI (1930), pp. 253–89.

[3] Arno C. Fieldner and W. E. Rice, "Annual Report of Research and Technologic Work on Coal: Fiscal year 1940," *U.S. Bur. Mines Inf. Circ. 7143* (1940), pp. 23–24.

constituents from the southern Illinois field. The net power consumed in crushing the constituents from −20 mesh to −150 mesh with the ash content of each, is shown in Table 1. It is shown that the durain, the hardest constituent, contains less ash than the clarain, although comparison of the values for fusain with any of the

TABLE 1

POWER REQUIRED TO CRUSH COAL CONSTITUENTS

Coal Constituent	Fusain	Vitrain	Clarain	Durain
Net horsepower hours per ton of −150-mesh product	1.8	3.8	5.1	13.6
Ash	15.6%	2.2%	8.3%	5.2%

others is even more startling. It has been recognized that fusain is the most easily crushed constituent, in spite of its relatively large percentage of ash.

SEPARATION AND CONCENTRATION METHODS

In some instances, highly sensitive specific-gravity methods will separate one or more of the banded ingredients from a crushed aggregate. Low-ash vitrain has been separated when the coal in which it occurred was crushed to pass a 10-mesh screen and then immersed in a solution of 1.23 specific gravity. However, low-ash fusain and durain may be of lower specific gravity.

Oil flotation has been employed in the laboratory to effect excellent separations of coal into its various components; this method could be employed commercially if there were necessity of such application.

CONCLUSION

As coal petrography defines the different macerals of coal more accurately, methods for isolating them will be perfected. Small amounts of such substances as resinite and cutinite will be isolated, analyzed, and tested. In such processes as hydrogenation, preparation will exclude the spores and cuticles and high-ash portions which are not readily liquefied. Much can be done in the preparation of some coals to improve their coking characteristics. Considerable has

been accomplished in the measurement of swelling characteristics of coal, but there are still lacking satisfactory test methods and standards for evaluating many of the phenomena which refined methods of preparation will make it possible to explore.

A most regrettable lack of imagination is demonstrated by the attitude which sees the salvation of the coal industry in an expanding use of coal purely as a raw fuel. While just now the trend is in that direction, it is an ephemeral condition at best. A sound program for the coal industry will not overlook the possibility of new materials of all kinds, plastics being only one of the many possibilities. In such a scheme coal petrography applied to preparation will have an important role.

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Topographic Mapping in Cooperation with the United States Geological Survey.

This Report is a Contribution of the Coal Division.

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